6. INGESTION

For many pollutants, an understanding of the ingestion exposure pathway is critical to accurately assessing potential health risks. This chapter provides a detailed presentation of the algorithms used in TRIM.Expo to assess, compare, and combine different ingestion pathways of exposure. Ingestion exposures are characterized in TRIM.Expo using the potential average daily dose (ADD). The ingestion exposure ADD represents the amount of pollutant that enters the mouth of the exposed individual over a defined exposure event or during a defined exposure duration. This chapter begins by providing an overview of the general approach used in TRIM.Expo to characterize the equivalent daily intake from an exposure medium. Of particular importance here is how the attributes of ingestion exposure define the spatial, temporal, and cohort resolution of the ingestion exposure algorithms. This is followed by a description of the media-specific algorithms used to estimate these exposures in TRIM.Expo. The chapter concludes with a presentation of the inputs and default values necessary to assess the ingestion exposure pathway.

6.1 OVERVIEW OF THE APPROACH

In Section 2.3.2, all exposure attributes relevant to exposure routes and pathways were organized into a set of three *key* exposure dimensions that has a significant impact on the structure of the exposure model (*e.g.*, on the exposure media included, the degree of spatial resolution, and the level of temporal and spatial aggregation). These three important *key* exposure dimensions of the exposure assessment problem were determined to be the (1) route of exposure, (2) time scale of an exposure event relevant to the pollutant's associated effects, and (3) degree of location dependence (*i.e.*, dependence of exposure on the location of the exposed subject).

In addition to incorporating the above exposure dimensions, ingestion exposure-event functions must also account for some unique modeling constraints. For example, slower rates of temporal variation in pollutant concentrations are exhibited in soil, water, vegetation, and animals because of their larger mass and tendency to retain pollutants. Furthermore, the food and water consumption data available from sources, such as EPA's Exposure Factors Handbook (U.S. EPA 1997b), provide only seasonal resolution which limits the use of this data for shorter-term assessments. Thus, ingestion exposure algorithms for media such as water, soil, and home-grown or locally-produced foods cannot support as high a degree of time and spatial resolution as inhalation exposures.

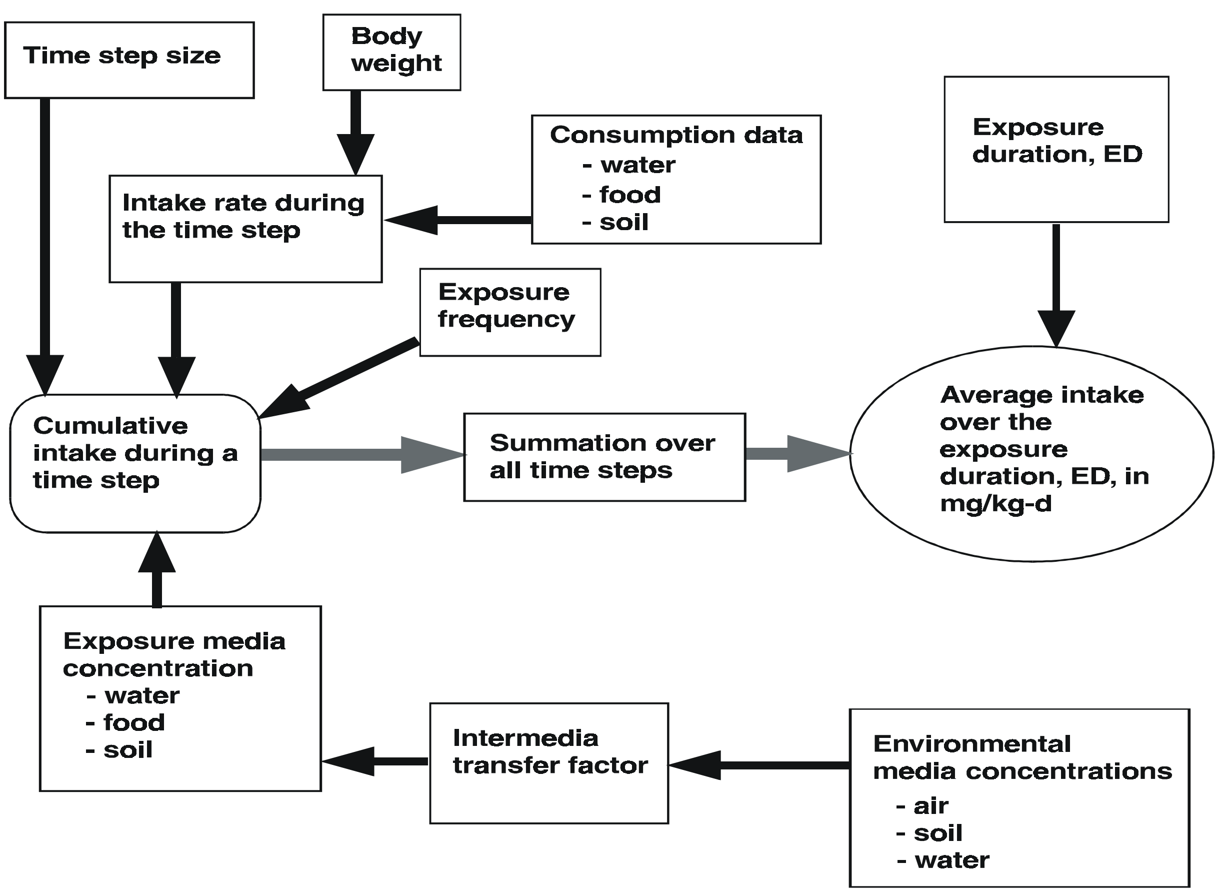
Based on the above constraints, the exposure-event functions for ingestion focus on pollutant concentration variations among exposure districts. Activities (*i.e.*, ingestion patterns) are characterized as daily equivalent intakes representative of each month. Concentrations are assessed at a time resolution of daily or greater and are then averaged for a representative exposure duration (*i.e.*, monthly).

To characterize an ingestion exposure, the ingestion intake algorithms require information on the following factors:

- The pollutant concentration in the exposure medium during an exposure event;
- The ingestion rate of the exposure medium during an exposure event;
- The body weight of the individual exposed or the body weight distribution of the exposed cohort;
- The fraction of the cohort's ingested water, soil, and food products that come from an exposure district with a specified pollutant concentration in the exposure medium; and
- The frequency of exposure events over the exposure duration.

Figure 6-1 below illustrates how this information is linked to characterize exposure and intake over an exposure duration.

Figure 6-1
An Illustration of How Information is Combined to Assess Ingestion Exposure over a Defined Exposure Duration



In order to organize this information into a form that expresses population exposure, an algorithm of the following form is used for each exposure medium considered in TRIM.Expo:

$$ADD_{z,m}(T) = \frac{\sum_t \left(\frac{I_{z,m}(k,l)}{BW_z} \right) C_m(i,k,l,t)\, EF_{z,m}(i,t)\, ET(t)}{T} \quad (6\text{-}1)$$

where:

$ADD_{z,m}(T)$	=	for individual or cohort *z* the average daily dose or intake of a pollutant from exposure medium *m* averaged over the time period *T*, which is one day or greater
$[I_{z,m}(k,l)/BW]$	=	the equivalent rate of intake of exposure medium *m* (expressed kg/d, L/d) over the time step *t* by individual or cohort *z* divided by that individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in the ingestion calculations, but are included here to provide consistency with the general exposure model presented in Chapter 2. This parameter can be obtained from EPA's Exposure Factors Handbook (U.S. EPA 1997b) for most exposure media
$C_m(i,k,l,t)$	=	the pollutant concentration in mg/kg in exposure medium *m* (*e.g.*, tap water, dairy products, meat, fish, vegetables) in exposure district *i* or location of the exposure media itself, averaged over the time step *t*. These concentrations are obtained from environmental samples or from a fate and transport model such as TRIM.FaTE
$EF_{z,m}(i,t)$	=	the frequency (fraction of days in the time step) that individual or cohort *z* from district *i* has contact with exposure medium *m* during time step *t*. This term is used to make adjustments for factors such as drinking water consumption that can be dispersed among several exposure districts. Typically, for food, the exposure frequency is set equal to the number of days in the time step because the exposure frequency is already implicitly incorporated into the daily intake rate.
$ET(t)$	=	the duration of time step *t* in months or days depending on the time resolution required
m	=	the exposure medium contacted (*e.g.*, air, water, food)

i	=	the geographical location in which the exposure takes place (*i.e.*, the exposure district) or the location of origin of the exposure media of concern (*e.g.*, drinking water).
k	=	microenvironment in which the exposure occurs, [*e.g.*, indoors at home; in a vehicle; indoors at work (not an important attribute for ingestion exposures)]
l	=	activity code that describes what the individual is doing at the time of exposure (*e.g.*, resting, working, preparing food, cleaning, eating)

The summation of pollutant exposures from all exposure media is over all time steps, *t*, that comprise the time period, *T*.

6.1.1 SELECTION OF POPULATION COHORTS

For ingestion exposures, important attributes that define cohorts include age, gender, exposure district, water supply, consumption of home-grown foods, and consumption of locally-produced foods. Table 6-1 summarizes the initial set of cohort attributes used in TRIM.Expo for ingestion exposures. These attributes were selected based on information available in key references such as EPA's Exposure Factors Handbook. There are fifteen primary attributes listed in this table that can be used to construct cohorts for ingestion exposure assessments, thus potentially leading to a large number of cohorts. However, many of the primary attributes can be combined (*e.g.*, home-grown foods can be aggregated into a single primary attribute instead of four separate categories as shown in Table 6-1). By combining attributes, the number of cohorts in the exposure analysis is significantly reduced.

Table 6-1
Primary Attributes of Exposure Cohorts

Primary Cohort Attributes
(1) Age
Child
Adult
(2) Gender
Male
Female
Exposure district
(3) Residential
(4) Work-school

Primary Cohort Attributes
(5) Water supply
Surface water
Ground water (public well)
Ground water (private well)
Home-grown food
(6) Fruits, vegetables, grains
(7) Dairy products
(8) Eggs
(9) Meat
Locally-produced food supplies
(10) Fruits, vegetables, grains
(11) Dairy products
(12) Eggs
(13) Meat
(14) Local fishing
(15) Local hunting

6.1.2 TIME RESOLUTION OF EXPOSURE EVENTS

The TRIM.Expo module is designed to allow the user to specify time steps ranging from hours to years. However, because of limited data on food consumption and biotransfer factors, the time resolution of ingestion exposure events can be set to either daily or monthly time steps. The time step can be increased or decreased, depending on the pollutants being studied and the time-scale of the health effects.

6.1.3 EXPOSURE MEDIA CONSIDERED

The ingestion exposure media that are included in the current conceptual design of TRIM.Expo are

- Surface water;
- Ground water;
- Soil and house dust;
- Home-grown fruits, vegetables, and grains;

- Home-produced eggs, dairy products, meat and fish; and
- Locally-produced fruits, vegetables, grains, dairy products, meat, and fish.

Surface water and ground water are both considered to be sources of drinking water, but direct ingestion of surface water and ground water can also occur during swimming and other recreational activities. Ingestion of soil is modeled to occur outdoors in a residential environment, whereas ingestion of dust is assumed to occur indoors at a residence or in a work environment.

Food supplies are categorized to be home-grown, locally-grown, or some combination of the two categories. TRIM.Expo defines *home-grown* foods as those foods produced on the land associated with a household and, for the most part, consumed within that household; whereas *locally-produced* foods are those that are produced in home gardens and commercial farms in contact with air, soil, and/or water that are in the study area. For the purposes of TRIM.Expo, it is assumed that the attributes associated with the consumption of locally-grown foods is the same for all districts within a study area (*e.g.*, urban air shed) and that the quantity of food that is designated as home-grown is applied separately based on whether the exposure district is urban, suburban, or rural.

For lipophilic pollutants (*e.g.*, dioxins, furans, polychlorinated biphenyls, pesticides) and for metals (*e.g.*, lead, mercury), exposures through food have been demonstrated to be the dominant contributors to total dose for non-occupationally exposed populations (Travis and Hester 1991). However, overall uncertainties in estimating potential doses through food chains are much larger than uncertainties associated with other exposure pathways (Jones et al. 1991, McKone and Daniels 1991, McKone and Ryan 1989).

6.1.3.1 Ingested Water

Ingested water is defined as water that is (1) consumed directly from the tap; (2) consumed in food and beverages; and/or (3) ingested during water recreation. The primary source of ingested water is tap water that is drawn from ground water, surface water, or some combination of the two sources. Water ingested during recreation could be either surface water or ground water.

Surface water includes water obtained from estuaries, lakes, rivers, and wetlands. Therefore, exposure to surface water can occur from the use of tap water and from recreational activities, such as swimming and other water sports. Ground water is found in the saturated zone of the subsurface environment. Human exposure to ground water can occur once it is withdrawn for tap/drinking water; used in cooking and processing foods; used for irrigation; used as water supply in recreational activities (*e.g.*, to fill a swimming pool); and/or supplied to animals reared/bred for human consumption.

6.1.3.2 Food

Currently TRIM.Expo includes several food exposure media, such as fruits, vegetables, grains, milk, dairy products, eggs, meat, and fish. TRIM.Expo differentiates between home-grown foods and locally-produced foods, and then focuses on which of these raw foods are produced and consumed within the set of exposure districts being considered in the risk and exposure analysis.

Fruits and vegetables are further divided into categories of unprotected and protected produce. Protected produce crops have skins or shells that are not usually consumed (*e.g.*, citrus fruits, peanuts, beans). Unprotected produce typically have no outer covering or have skins or shells that are commonly consumed (*e.g.*, leafy vegetables, grapes, most grains). In addition, vegetables are distinguished between those that have edible parts that grow above the ground (*i.e.*, above-ground crops) versus those that are root crops (*i.e.*, below-ground crops). In the case of root (below-ground) crops, EPA's Exposures Factors Handbook (U.S. EPA 1997b) does not differentiate between protected or unprotected produce. Table 6-2 provides examples of fruits, vegetables, and grains defined by the above categories.

Table 6-2
Taxonomy of Food Types Categorized as Fruits, Vegetables, and Grains

Type of Crop	Protected/ Unprotected	Fruits	Vegetables	Grains
Above-ground crops	unprotected	grapes, berries, apples	lettuce, broccoli	wheat, barely oats
	protected	citrus	beans, peas	none considered
Below-ground crops (root crops)		none considered	carrots, radishes, peanuts, potatoes	none considered

Cooked and Processed Food

Exposures to pollutants in cooked and processed foods depend on the preparation techniques used to combine and convert raw foods into edible, consumption food products. Meats, eggs, dairy products, and grains are almost always processed and cooked prior to human consumption. Since cooking and food processing can result in the transformation of many pollutants, intermedia transfer factors are needed to characterize how preparation and cooking alter raw food products. However, for the most part, such factors are unavailable. EPA's Exposure Factors Handbook (U.S. EPA 1997b) contains some of this information.

Uncooked Food

Most fruits and some vegetables are served uncooked, reducing the need for intermedia transfer factors to distinguish differences between ambient pollutant concentrations in the vegetation and the pollutant concentration at the time of consumption. Even though fruits and vegetables can be washed before they are eaten, current research suggests that for fine particles and pollutants dissolved in the lipid phase of the vegetation, washing does little to reduce pollutant concentration (Jones et al. 1991) and thus, it may not be necessary to incorporate a factor that accounts for how washing alters pollutant concentrations.

6.1.3.3 Soil and Dust

Three soil categories, classified by the depth of soil–surface soil, root zone soil, and vadose zone soil–are used to assess soil contamination in the outdoor environment (see the TRIM.FaTE TSD, Volumes I and II for more information; U.S. EPA 1999a, b). Both surface soil and root zone soil are considered to be sources of pollutant transfers from soil to vegetation. Surface soil is also assumed to be the primary source for direct ingestion of soil outdoors.

In the indoor environment, the hand-to-mouth activities of children and adults are assumed to give rise to contact with house dust as opposed to actual soil ingestion. House dust suspended in the indoor air environment originates from three sources: (1) airborne particles that penetrate from outdoor air to indoor air; (2) surface soil and dust tracked into buildings on shoes or clothes, by pets, or other vectors; and (3) a variety of sources related to occupant activities, material degradation, and household products. In the current version of TRIM.Expo, the pollutant concentration in house dust is assumed to be equal to that in surface soil.

6.1.4 EXPOSURE LOCATIONS

The pollutant concentrations in the exposure media of drinking water, locally-grown foods, and recreational food products are likely to be either highly dependent on the original location of the media or aggregated among several exposure districts. The magnitude of exposure to an individual or cohort is not strongly dependent on the exposure district in which the receptor resides; instead, the magnitude of exposure will depend on the fraction of food and water supply that comes from local sources and on their proximity to sources of pollution. The pollutant concentrations in these exposure media are considered to be weakly dependent on the resident location of the receptor since the driving factor for exposure is the pollutant concentrations found in the locations from where water and food are obtained, rather than the pollutant concentrations found in the area where the receptor resides. In cases where food and water distribution systems are not well characterized, pollutant concentrations in all exposure media are aggregated among several exposure districts (*i.e.*, those that supply drinking water and/or food) and then delivered to the various population cohorts.

In contrast to exposure media that are weakly dependent on the receptor location, exposure media such as home-grown foods, soil, and house dust have pollutant concentration levels that depend almost completely on pollutant levels in the air and soil of the exposure district in which the exposed receptor resides.

6.1.4.1 Residential Exposure Locations

For the modeling purposes of TRIM.Expo, it is assumed that ingestion exposure events occur mostly in the residential microenvironment located in the residential exposure district of the exposed receptor(s). Ingestion of home-grown foods, soil, and/or dust are assumed to occur exclusively at the primary residential location of the exposed individual or cohort. Ingestion of water and locally-grown foods are assumed to take place primarily in the residential exposure districts. However, ingestion of the above products can also take place at work and/or at restaurants that are not necessarily in the residential exposure district of the individual or cohort. However, since these latter pollutant concentrations are aggregated among several exposure districts, the exact location where water or locally-grown foods are consumed is not important. In such cases, the information that is needed is (1) the quantity of locally-grown foods and locally-supplied water consumed by an individual or cohort and (2) the exposure districts from which the food and water are obtained.

6.1.4.2 Other Exposure Locations

As noted above, the exposure location for pollutants found in water and locally-grown foods is primarily residential, but the estimation of the pollutant levels in food and water are based on a combination of several exposure districts in which these pollutants are found. A similar approach is used for exposure to pollutants found in meat and fish derived from local hunting and fishing. The exposure location is assumed to be the residence of the cohort, but the pollutant concentrations in the watershed or habitat in which hunting and fishing take place.

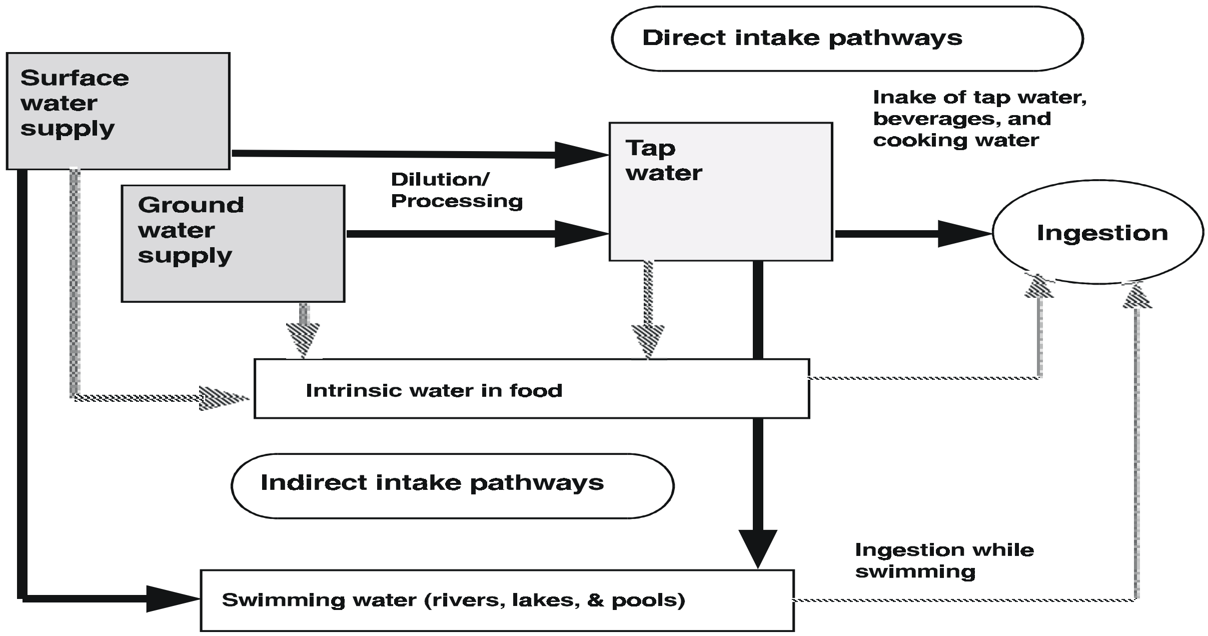
6.2 PRESENTATION OF THE MODEL ALGORITHMS BY EXPOSURE MEDIA

This section presents the ingestion exposure algorithms, organized by exposure media (*i.e.*, water, soil, food) that are currently used in TRIM.Expo to express the intake of pollutant concentrations found in the environmental media.

6.2.1 INGESTED WATER

Figure 6-2 illustrates the ingestion pathways of surface water and ground water for humans. TRIM.Expo currently incorporates only the direct ingestion of tap water that is derived from surface water or ground water.

Figure 6-2
Exposure Pathways Considered for Surface and Ground Water



Tap water intake includes household drinking water that is consumed directly or consumed indirectly in a beverage (*e.g.*, orange juice, soft drinks, coffee, tea) or in adding intrinsic water to food. For the direct ingestion of tap water, the applicable exposure algorithm is:

$$ADD_{z,tw,i}(T) = \frac{\sum_t \left(\frac{I_{z,tw}(k,l)}{BW_z} \right) C_{tw}(i,k,l,t) EF_{z,tw}(i,t) ET(t)}{T} \qquad (6\text{-}2)$$

where:

$C_{tw}(i,k,l,t)$ = pollutant concentration in tap water, mg/L.

$[I_{z,tw}(k,l)BW_z]$ = the rate of intake of tap water (*tw*), L/kg/d, by individual or cohort *z* divided by that individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.

$EF_{z,tw}(i,t)$ = the exposure frequency, number of days per month equivalent, that individual or cohort *z* obtains tap water from exposure district *i* (this is likely to be location independent).

Pollutant concentration in tap water may not be directly measurable or derivable from the output of models, such as TRIM.FaTE. In such cases, intermedia transfer factors can be used to calculate the pollutant concentrations in tap water based on pollutant concentrations found in surface water and ground water:

$$C_{tw}(i,k,l,t) \quad = \quad PF(w)\ C_{sw}(i,k,l,t) \qquad (6\text{-}3)$$

$$= \quad PF(w)\ C_{gw}(i,k,l,t) \qquad (6\text{-}4)$$

PF(w) = the intermedia transfer that expresses the concentration in tap water relative to ground or surface water used in exposure district *i*. *PF(w)* is the processing dilution factor that accounts for the removal of pollutants by processing. In the current version of TRIM.Expo, *PF(w)* is set to 1 but can be set to a value specific to each exposure district.

The Environmental Fate and Effects Division of EPA's Office of Pesticide Programs (OPP) is in the process of producing a document that discusses the concept of the intermedia transfer (*PF(w)*) that relates the pollutant concentration in tap water to that found in ground water or surface water.

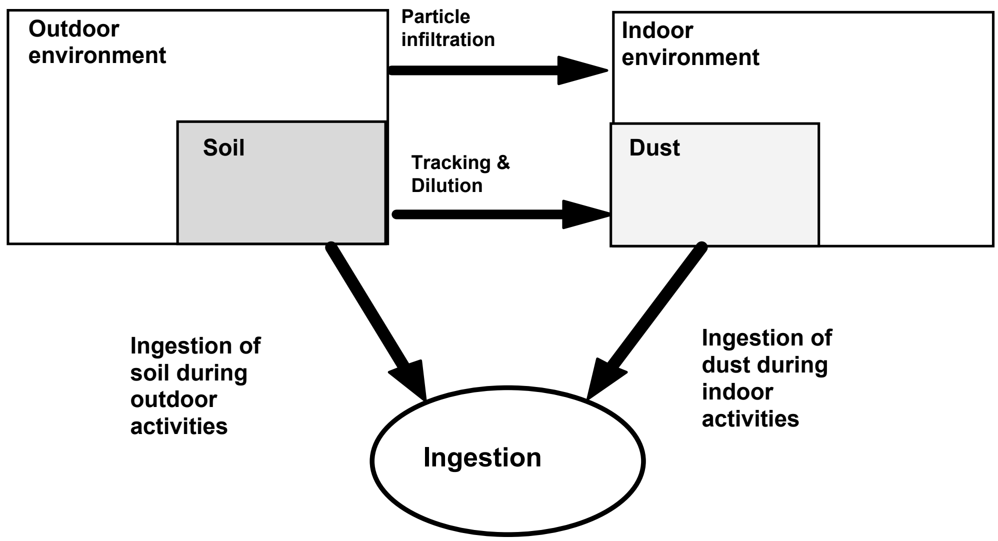
6.2.2 INGESTION OF SOIL AND HOUSE DUST

Both adults and children inadvertently ingest small amounts of soil through hand-to-mouth activities. Children who spend a great deal of time outdoors contact and ingest soil, and adults ingest soil through activities such as gardening, outdoor labor, and cleaning. In some cases, individuals suffer from a condition called *pica behavior*, and are known to intentionally consume large quantities of soil.

Several studies have been conducted to characterize soil ingestion by children (*e.g.*, see U.S. EPA 1997b, Stanek et al. 1998, Calabrese and Stanek 1995, Sedman and Mahmood 1994, Thompson and Burmaster 1991, Davis et al. 1990). Some of these studies make use of soil loading on children's hands in combination with observations of hand-to-mouth activity to estimate soil uptake. Another approach to estimating soil ingestion uses tracer elements in feces. The process involves analyzing both the feces of children and the soil in their playgrounds for elements that are thought to be poorly absorbed in the gut, such as aluminum, silicon, and titanium. Then, assuming that there are no non-soil sources of these elements and using a fecal excretion rate, the soil ingestion for each child is estimated based on the mass of each tracer element detected in the feces relative to that found in soil. In such studies, hospitalized children who have little contact with soil are often used as control groups.

Hand-to-mouth activities lead to the ingestion of pollutants in soil (outdoors) and in house dust (indoors). Pollutants in house dust are attributable in part to pollutants found in the surface soil surrounding the residence because of the resuspension of outdoor surface soil, and its infiltration through windows and openings, and its subsequent deposition onto indoor surfaces. The pollutants can also be brought indoors from the outdoor soil by soil tracking (*i.e.*, soil carried into the house by shoes, clothing, and pets). Figure 6-3 illustrates soil ingestion pathways that are considered in TRIM.Expo.

Figure 6-3
Exposure Pathways Considered for Contact with Soil and House Dust



6.2.2.1 Soil Ingestion (Outdoors)

For direct ingestion of surface soil in the residential outdoor environment, the applicable exposure algorithm is:

$$ADD_{z,ss,i}(T) = \frac{\sum_t \left(\frac{I_{z,ss}(k,l)}{BW_z} \right) C_{ss}(i,k,l,t) EF_{z,ss}(i,t) ET(t)}{T} \qquad (6\text{-}5)$$

where:

$[I_{z,ss}(k,l)/BW]$ = the annually averaged daily rate of intake of surface soil (*ss*), kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.

$EF_{z,ss}(i,t)$ = the exposure frequency, which is the fraction of days in a month that individual or cohort *z* has contact with outdoor soil in exposure district *i*. This factor is used to make adjustments for time within or outside of the exposure district - the number of days per month outside with soil contact is already accounted for in the parameter above.

$C_{ss}(i,k,l,t)$ = the pollutant concentration, mg/kg, in the surface soil or outside surface dust (of urban areas) for exposure district *i* during the time step *t*.

6.2.2.2 Dust Ingestion (Indoors)

For the direct ingestion of pollutants from house dust in the indoor environment, it is assumed that residential surface soil is the source of the dust pollutants. The applicable exposure algorithm is:

$$ADD_{z,hd,i}(T) = \frac{\sum_t \left(\frac{I_{z,hd}(k,l)}{BW_z}\right) C_{hd}(i,t) EF_{z,hd}(i,t) ET(t)}{T} \qquad (6\text{-}6)$$

where:

$C_{hd}(i,t)$ = the pollutant concentration, mg/kg, in the house dust (*hd*) of exposure district *i* during the time-step *t*.

$[I_{z,hd}(k,l)/BW]$ = the annually averaged daily rate of intake of soil, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation,

$EF_{z,hd}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* has contact with house dust in exposure district *i*.

The concentration of a pollutant in house dust is calculated from two intermedia transfer factors:

$$C_{hd}(i,k,l,t) = f_{hds} IN_{ss}(i,t) C_{ss}(i,t) + (1 - f_{hds})\left(\frac{IN_{ap}(i,t)}{\rho_{ap}}\right) C_{ap}(i,t) \qquad (6\text{-}7)$$

$C_{ss}(i,t)$ = the pollutant concentration in soil of exposure district *i* during time step *t*, mg-kg.

$C_{ap}(i,t)$ = the pollutant concentration in the particulate phase of exposure district *i* during time step *t*, mg-m^3.

f_{hds} = the fraction of indoor dust that originates from outdoor soil. The remaining fraction is assumed to originate from particulate matter in air. Currently, this fraction is set to 0.5.

$IN_{ss}(i,t)$ = the combined soil infiltration and soil tracking factor that expresses the likely increase or decrease of pollutant concentration in indoor soil relative to outdoor surface soil in exposure district *i*. TRIM.Expo currently sets $IN_{ss}(i,t)$ to 1 but it can be set to a value specific to each exposure district and each time step.

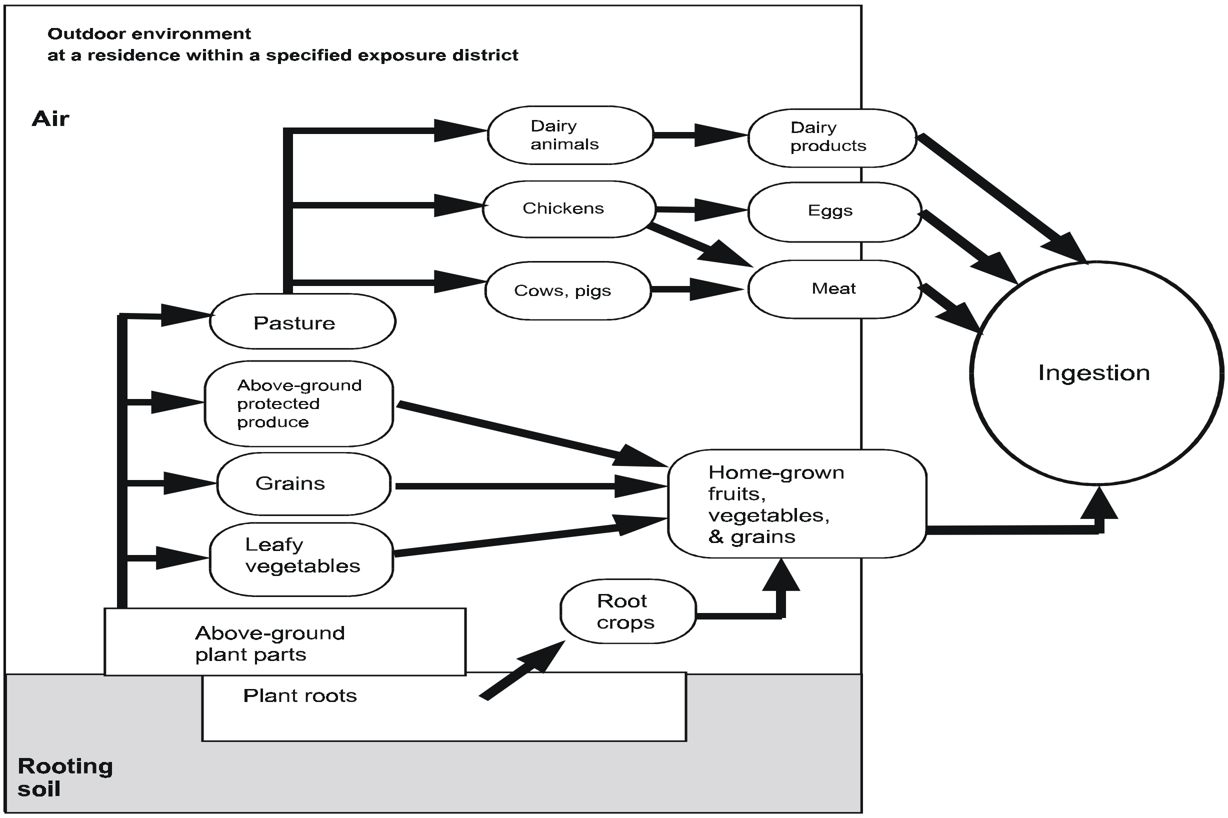
$[IN_{ap}(i,t)/\rho_{ap}]$ = the particle infiltration factor that expresses the likely increase or decrease of pollutant concentration in indoor dust relative to pollutant concentration in outdoor particulate matter in exposure district *i*. ρ_{ap} is the density of airborne particles of ~2,400 kg-m^3. In the current version of TRIM.Expo, $IN_{ap}(i,t)$ is set to 1 but can be set to a value specific to each exposure district and each time step.

6.2.3 INGESTION OF POLLUTANTS IN HOME-GROWN PRODUCE OR HOME-BRED ANIMALS

Soil pollutants can be transferred to the edible parts of vegetation from surface soil by resuspension and deposition, rain splash, volatilization followed by partitioning, and by root uptake for below-ground vegetation (Jones et al. 1991). The level of exposure to the soil pollutants found in vegetation food products often depends on translocation (*i.e.*, the process by which a pollutant is transferred from one part of a plant to another). Translocation can cause significant differences in pollutant concentrations in the total plant and the edible portion of the plant (*i.e.,* fruit, seeds). In addition, ingestion of contaminated soil or grains by animals reared/bred for human consumption can lead to contaminated, animal-based food products, such as meat, milk, dairy products, and eggs.

For the purposes of TRIM.Expo, home-grown foods are defined as foods grown on the land associated with a household and, for the most part, consumed within that household. Figure 6-4 illustrates the exposure pathways considered in constructing food-based exposures from home-grown foods and the algorithms used for modeling pollutant exposures from home-grown food products are discussed in the sections below. In the TRIM.Expo framework, home-grown foods are studied in a single exposure district. To calculate individual or cohort consumption of home-grown food products, the annual average consumption of the food product for individual or cohort z is derived from the national food consumption survey data (CSFII 1996) and then used to calculate the fraction that can be allocated to home-grown foods.

Figure 6-4
Exposure Pathways Considered for Contact with Food Products



6.2.3.1 Vegetables, Fruits, and Grains

Vegetables, fruits, and grains include leafy vegetables (*e.g.*, cabbage, cauliflower, broccoli, celery, lettuce, spinach), exposed produce (*e.g.*, apples, pears, berries, cucumber, squash, grapes, peaches, tomatoes, string beans), protected produce or root crops (*e.g.*, carrots, beets, turnips, potatoes, legumes, melons, citrus fruits) and grains (*e.g.*, wheat, corn, rice, barley, millet).

Pollutants in the root zone soil gas and liquid can be taken up by plant roots and potentially transferred to above-ground plant parts in the transpiration stream. The ease with which non-ionized pollutants are taken up from the soil into root material is influenced by the pollutant's octanol/water partition coefficient, K_{ow}, which is commonly used as a measure of lipophilicity and water solubility. Pollutants with high K_{ow} values tend to either be strongly sorbed onto organic material in the root, making them less available for movement in the transpiration stream, or sorbed onto organic material in the soil, reducing their availability to root uptake. Increases in the water solubility of a pollutant tend to increase the amount of pollutant available for uptake from the soil water and increase the likelihood of movement with the transpiration stream; however, the root membrane of most plants restricts uptake of highly soluble or ionized species.

The algorithm for ingestion of pollutants in above-ground fruits, vegetables, and grains has the general form:

$$ADD_{z,fvg,i}(T) = \frac{\sum_t \left(\frac{I_{z,g}(k,l)}{BW_z} \right) C_g(i,t) EF_{z,g}(i,t) ET(t)}{T} + \frac{\sum_t \left(\frac{I_{z,efv}(k,l)}{BW_z} \right) C_{efv}(i,t) EF_{z,efv}(i,t) ET(t)}{T} + \frac{\sum_t \left(\frac{I_{z,pfv}(k,l)}{BW_z} \right) C_{pfv}(i,t) EF_{z,pfv}(i,t) ET(t)}{T} \quad (6\text{-}8)$$

where:

$C_g(i,t)$	=	the pollutant concentration, mg/kg, in the grains (*g*) of exposure district *i* during the time step *t*.
$C_{efv}(i,t)$	=	the pollutant concentration, mg/kg in the exposed fruits and vegetables (*efv*) of exposure district *i* during the time step *t*.
$C_{pfv}(i,t)$	=	the pollutant concentration, mg/kg in the protected fruits and vegetables (*pfv*) of exposure district *i* during the time step *t*.

[Note that these three concentrations must be obtained from measurements or from a model such as TRIM.FaTE].

$[I_{z,g}(k,l)/BW_z]$	=	the monthly or seasonally averaged daily rate of intake of grains, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.
$[I_{z,efv}(k,l)/BW_z]$	=	the monthly or seasonally averaged daily rate of intake of exposed fruits and vegetables, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation,
$[I_{z,pfv}(k,l)/BW_z]$	=	the monthly or seasonally averaged daily rate of intake of protected fruits and vegetables, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation,

$EF_{z,g}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes home-grown grains in exposure district *i*. If the daily intake rate implicitly includes the exposure frequency, then this term is set equal to 1.

$EF_{z,efv}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes home-grown exposed fruits and vegetables in exposure district *i*. If the daily intake rate implicitly includes the exposure frequency, then this term is set equal to 1.

$EF_{z,pfv}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes home-grown protected fruits and vegetables in exposure district *i*. If the daily intake rate implicitly includes the exposure frequency, then this term is set equal to 1.

According to Yang and Nelson (1986), about half of all produce (*i.e.*, fruits, vegetables) consumed by humans consists of leafy vegetables and exposed produce that intercept pollutants from the atmosphere. The remaining half consists of protected produce or root crops, where pollutant transfer to the edible portion is primarily by root uptake. All grain crops are assumed to be exposed primarily to air pollutants.

6.2.3.2 Dairy Products

To calculate human exposures to pollutants found in dairy products, the biotransfer factors for milk versus the pollutant intake by dairy cattle must be determined, along with the parameters that describe the pasture, water, and soil intake rates of dairy cattle. For the purposes of TRIM.Expo, pasture is defined to be all foodstuffs that are grown on the farm to feed the animals (*e.g.*, open pasture grass, grains, corn).

The algorithm for ingestion of pollutants in dairy products has the form:

$$ADD_{z,dp,i}(T) = \frac{\sum_t \left(\frac{I_{z,dp}(k,l)}{BW_z} \right) C_{dp}(i,t) EF_{z,dp}(i,t) ET(t)}{T} \tag{6-9}$$

where:

$C_{dp}(i,t)$ = the pollutant concentration, mg/kg, in the dairy products (*dp*) of exposure district *i* during the time step *t* obtained from measurements or from a model such as TRIM.FaTE.

$[I_{z,dp}(k,l)/BW_z]$ = the monthly or seasonally averaged daily rate of intake of dairy products, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.

$EF_{z,dp}(i,t)$ = the exposure frequency, expressed as the fraction of days per month equivalent, that individual or cohort *z* consumes home-grown dairy products in exposure district *i*. If the daily intake rate implicitly includes the exposure frequency, then this term is set equal to 1.

6.2.3.3 Eggs

To calculate human exposures to pollutants found in eggs laid by home-grown hens, the biotransfer factors for eggs versus the pollutant intake by chickens, and the parameters that describe the feed, water, and soil intake rates of chickens must be characterized.

The algorithm for ingestion of pollutants in eggs has the form:

$$ADD_{z,egg,i}(T) = \frac{\sum_t \left(\frac{I_{z,egg}(k,l)}{BW_z}\right) C_{egg}(i,t) EF_{z,egg}(i,t) ET(t)}{T} \qquad (6\text{-}10)$$

where:

$C_{egg}(i,t)$ = the pollutant concentration, mg/kg, in eggs in the exposure district *i* during the time step *t* obtained from measurements or from a model such as TRIM.FaTE.

$[I_{z,egg}(k,l)/BW_z]$ = the monthly or seasonally averaged daily rate of intake of eggs, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation,

$EF_{z,egg}(i,t)$ = the exposure frequency, expressed as the fraction of days per month equivalent, that individual or cohort *z* consumes home-grown eggs in exposure district *i*. If the daily intake rate implicitly includes the exposure frequency, then this term is set equal to 1.

6.2.3.4 Meat and Poultry

To calculate human exposures to pollutants found in meat, the biotransfer factors for meat versus pollutant intake by animals reared/bred for human consumption and the parameters that describe the pasture, water, and soil intake rates of these animals must be quantified. For the purposes of TRIM.Expo, cattle is used to represent **all** animals that are reared/bred for human consumption.

The algorithm for ingestion of pollutants found in meat has the form:

$$ADD_{z,mp,i}(T) = \frac{\sum_t \left(\frac{I_{z,mp}(k,l)}{BW_z}\right) C_{mp}(i,t)\, EF_{z,mp}(i,t)\, ET(t)}{T} \qquad (6\text{-}11)$$

where:

$C_{mp}(i,t)$	=	the pollutant concentration, mg/kg in the home-grown meat and poultry (*mp*) of exposure district *i* during the time step *t* obtained from measurements or from a model such as TRIM.FaTE.
$[I_{z,mp}(k,l)/BW_z]$	=	the average daily rate of intake of meat and poultry, kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.
$EF_{z,mp}(i,t)$	=	the exposure frequency of meat and poultry consumption of individual or cohort *z* in exposure district *i* (expressed as the fraction of days per month equivalent). If the daily intake rate implicitly includes the exposure frequency, then this term is set equal to 1.

6.2.4 LOCALLY-GROWN COMMERCIAL FOODS

The following subsections describe algorithms for estimating intake of pollutants found in locally-grown foods. These types of algorithms have been previously developed by McKone and Ryan (1989), McKone and Daniels (1991), Travis and Blaylock (1992), and McKone (1993a, b, c). The form and ranges of values used in these models have been validated for a limited number of compounds by Bennett (1981, 1982) and by Travis and Blaylock (1992).

Locally-grown foods (*i.e.*, grown in home gardens and commercial, local farms) are defined as foods that are not only produced, but also consumed within the same urban air shed being modeled by TRIM.Expo. The pollutant concentrations in air, soil, and/or water that are used to assess concentrations in locally-grown foods make use of the average pollutant concentration in the locations of farms producing such foods. For modeling purposes, it is ideal if distributions for describing the local concentrations of pollutants in produce, grain, milk and dairy products, meat, eggs, and fish are available; but if these values are not available, they must be developed.

6.2.4.1 Vegetables, Fruits, and Grains

The algorithms used to calculate intake of pollutants in locally-grown vegetables, fruits, and grains are the same as those provided in Section 6.2.3.1 with the following replacements:

$EF_{z,g}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes locally-produced grains in exposure district *i*. As with home-grown produce and home-bred animals, if the daily intake rate of locally-grown produce implicitly includes the locally-grown produce exposure frequency, then this term is set equal to 1.

$EF_{z,efv}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes locally-produced exposed fruits and vegetables in exposure district *i*. As with home-grown produce and home-bred animals, if the daily intake rate of locally-grown produce implicitly includes the locally-grown produce exposure frequency, then this term is set equal to 1.

$EF_{z,pfv}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes locally-produced protected fruits and vegetables in exposure district *i*. As with home-grown produce and home-bred animals, if the daily intake rate of locally-grown produce implicitly includes the locally-grown produce exposure frequency, then this term is set equal to 1.

$C_g(avg,t)$ replaces $C_g(i,t)$, where $C_g(avg,t)$ is the averaged pollutant concentration, mg/kg, in grains based on the average concentration in the locations where local foods are produced during the time step *t*.

$C_{efv}(avg,t)$ replaces $C_{efv}(i,t)$, where $C_{efv}(avg,t)$ is the averaged pollutant concentration, mg/kg, in exposed fruits and vegetables based on the average concentration in the locations where local foods are produced during the time step *t*.

$C_{pfv}(avg,t)$ replaces $C_{pfv}(i,t)$, where $C_{pfv}(avg,t)$ is the averaged pollutant concentration, mg/kg, in protected fruits and vegetables based on the average concentration in the locations where local foods are produced during the time step *t*.

6.2.4.2 Dairy Products

The algorithms used to calculate intake of pollutants from locally-produced dairy products are the same as those provided in Section 6.2.3.2 with the following replacements:

$EF_{z,dp}(i,t)$ = the exposure frequency, expressed as the fraction of days per month equivalent, that individual or cohort *z* consumes locally-produced dairy products in exposure district *i*. As with home-grown produce and home-bred animals, if the daily intake rate of locally-produced dairy products implicitly includes the locally-produced dairy products exposure frequency, then this term is set equal to 1.

$C_{dp}(avg,t)$ replaces $C_{dp}(i,t)$, where $C_{dp}(avg,t)$ is the spatially averaged pollutant concentration, mg/kg, in the milk derived from all suburban and rural exposure districts where local dairy products are produced during the time step *t*.

6.2.4.3 Eggs

The algorithms used to calculate intake of pollutants found in locally-produced eggs are the same as those provided in Section 6.2.3.3 with the following replacements:

$EF_{z,egg}(i,t)$ = the exposure frequency, fraction of days per month equivalent, that individual or cohort *z* consumes locally-produced eggs in exposure district *i*. As with home-grown produce and home-bred animals, if the daily intake rate of locally-produced eggs implicitly includes the locally-produced eggs exposure frequency, then this term is set equal to 1.

$C_{e}(avg,t)$ replaces $C_{egg}(i,t)$, where $C_{egg}(avg,t)$ is the averaged pollutant concentration, mg/kg, in eggs based on the average concentration in the locations where eggs are produced locally during the time step *t*.

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6.2.4.4 Meat and Poultry

The algorithms used to calculate intake of pollutants found in locally-produced meat and poultry are the same as those provided in Section 6.2.3.4 with the following replacements:

$EF_{z,mp}(i,t)$ = the exposure frequency, number of days per month equivalent, that individual or cohort *z* consumes locally-produced meat products in exposure district *i*. As with home-grown produce and home-bred animals, if the daily intake rate of locally-produced meat products implicitly includes the locally-produced meat products exposure frequency, then this term is set equal to 1.

$C_{mp}(avg,t)$ replaces $C_{mp}(i,t)$, where $C_{mp}(avg,t)$ is the averaged pollutant concentration, mg/kg, in meat based on the average concentration in the locations where local meat products are produced during the time step *t*.

6.2.4.5 Fish (Commercial, Subsistence, and Recreational)

Exposures to pollutants that are found in fish are assumed to occur only on a local scale, with no residential (home) scale exposures. The algorithm for ingestion of pollutants found in fish has the form:

$$ADD_{z,f,i}(T) = \frac{\sum_t \left(\frac{I_{z,f}(k,l)}{BW_z}\right) C_f(avg,t) EF_{z,f}(i,t) ET(t)}{T} \qquad (6\text{-}12)$$

where:

$[I_{z,f}(k,l)/BW_z]$ = the average daily rate of intake of fish (*f*), kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.

$C_f(avg,t)$ = the spatially or market averaged pollutant concentration, mg/kg, in the fish of all exposure districts in the air shed being considered during the time step *t*.

$EF_{z,f}(i,t)$ = the exposure frequency, expressed as the fraction of days per month or its equivalent), that individual or cohort *z* in exposure district *i* consumes locally-caught fish. When the daily intake rate implicitly includes exposure frequency this term can be set equal to 1.

The TRIM.Expo module utilizes three types of cohorts to reflect differences in the exposure frequency to fish – those who buy and consume locally-raised fish, but do not catch their own fish; those who consume locally-raised fish that they also catch on their own (*e.g.*, recreational fishermen); and those who are subsistence fishermen who catch fish for a living and also eat the fish that they catch.

6.2.5 RECREATIONAL SPORT MEAT (HUNTING)

Exposures to pollutants found in game animals (*e.g.*, deer, water fowl) are assumed to occur only on a local scale, with no residential (home) scale exposures. The algorithm for ingestion of pollutants in meat from game animals is as follows:

$$ADD_{z,sm,i}(T) = \frac{\sum_t \left(\frac{I_{z,sm}(k,l)}{BW_z} \right) C_{sm}(avg,t) ET(t)}{T} \qquad (6\text{-}13)$$

where

$[I_{z,sm}(k,l)/BW_z]$ = the time-step averaged daily rate of intake of sport meat (*sm*), kg/kg/d, by individual or cohort *z* divided by a representative individual's body weight (*BW*). The microenvironment and activity codes *k* and *l* are not used in this calculation.

$C_{sm}(avg,t)$ = the averaged pollutant concentration, mg/kg, in the meat of game animals residing in the air shed being considered during the time step *t*.

There is currently no separate algorithm available in TRIM.Expo to determine concentrations in game animal tissues. This information must be obtained from available data or can be obtained from the output of TRIM.FaTE.

6.3 INTEGRATION OF EXPOSURES ACROSS MULTIPLE INGESTION MEDIA

The integration of ingestion exposures across multiple media for an individual or cohort is based on matching time scales. All ingestion intakes within a given time step are summed, and currently, relatively large time steps (monthly) are used in TRIM.Expo, such that the time aggregation of ingestion exposures is straight forward and does not introduce a significant source of uncertainty or confusion. Even daily aggregation of ingestion exposures should not be difficult since TRIM.Expo is capable of working in hourly time steps. However, more importantly, if TRIM.Expo is used to integrate ingestion exposures in hourly time steps, then a comprehensive inventory of micro-activity data on the daily water and food intake and hand-to-mouth activities of cohorts and individuals are needed. Such data are not yet available.

With regard to ingestion, some products are bolous exposures which are discrete while others are aggregated (*e.g.*, a beef meal would be associated with a specific farm and have a spatially dependent concentration, while milk would likely be a diluted exposure composed of a mixture of milk from all neighboring dairy farms). Therefore, where appropriate these exposures should be modeled on a meal-by-meal basis (*i.e.*, for each meal, the source of the food item is randomly selected based on the proportion of its contribution to the total commodity load and, thus, the pollutant concentration in the food item would be specific to that farm). Probabilistic approaches would be repeated for each meal to get a more representative estimate of dietary exposure. This process is described in more detail in EPA's guidance on health risks associated with multiple exposure pathways to combustor emissions (U.S. EPA 1997d).

The population risk (*i.e.*, incidence of effects) from pollutants that are believed to exhibit non-threshold mechanisms (*i.e.*, linear carcinogens) can be estimated based on the amount of pollutants entering the food supply each year (U.S. EPA 1997d). This method, as specified in EPA guidance (U.S. EPA 1997d), uses the annual amount of food produced in various food-producing regions of the study area as the metric of concern and then estimates the subsequent exposures to pollutants in the food.

6.4 DISCUSSION OF ALGORITHM INPUTS AND VALUES

An important attribute of exposure models is the ability to account for factors that control variation in human contact (*i.e.*, age, gender, location, activity patterns). Exposure assessments for ingestion pathways use of a number of factors that are both variable and uncertain. For each relevant population cohort, a number of exposure factors described in the previous sections can be used to characterize contact and intake. These factors are used to describe specific ingestion behaviors (*e.g.*, rates of ingestion for specific media such as fish and water for specific cohorts) or to describe the characteristics of the populations themselves (*e.g.*, body weight). For each of these parameters, it is necessary to develop a range of values that represent the population cohorts. Currently, OAQPS is compiling and evaluating data for each parameter for TRIM.Expo. The EPA's Exposure Factors Handbook (U.S. EPA 1997b) is one source being used extensively to derive such factors. EPA's National Center for Environmental Assessment (NCEA) is currently conducting research on how to derive distributions for many of the ingestion exposure factors identified in this chapter. When these distributions become available, they will be adopted as appropriate for use in TRIM.Expo. In the meantime, efforts are underway by OAQPS and other EPA program offices to develop exposure factors and associated distributions for specific parameters for use in risk assessments. When these are available, they will be published and be the subject of subsequent reviews.